§5. Development of a High Efficiency Cryocooler for Cryogen-free Cooling System

Masuyama, S. (Oshima National College Maritime Technol.),
Iwamoto, A.

Pulse tube cryocoolers (PTCs) are possible to produce easily the environment of very low temperatures without mechanical moving part in the cold part. From this advantage, PTCs have been utilized for advancing the construction of various superconducting systems. In order for technological innovation to progress further, high efficiency PTCs will be required. Furthermore, the problem of an increase in the price of liquid helium in the last few years will make it accelerate.

On the other hand, the advantage of cryogen-free systems is that a refrigerant facility is unnecessary. To construct this superb system, the directly cooling method with regenerative cryocooler will be one of the leading candidates. However, it is difficult to cool all areas in a large system by using one cryocooler. From the point of view, we have proposed a distributed cooling method[1)] that can be adapted for a large system including a fusion system. This concept is that the many cryocoolers, which are distributed to each cooling part, directly cool a whole system. Therefore, high efficiency cryocoolers are required at the desired temperatures.

This study is aiming at achievement of high efficiency single stage PTC with four-valve operation mode. A schematic diagram of the developing PTC is shown in Fig. 1. This PTC is operated by four-valve mode with four solenoid valves that are controlled by suitable timing at the operating frequency of 2 Hz. Two needle valves, which are located at the warm end of pulse tube, adjust the alternative flow rate of helium gas. The total length from the warm end (room temperature) to the cold end is approximately 250 mm. This PTC is operated with a compressor of an electric input power of 7.3 kW. The initial charging pressure of helium gas is 1.6 MPa. A photo of the four-valve PTC at room area is shown in Fig. 2. Two solenoid valves of the right side connect to the warm end of regenerator, and two solenoid valves of the left side and two needle valves connect to the warm end of pulse tube.

To achieve the high efficiency, two regenerator materials were packed in the regenerator as a two-layer structure. One is a stainless steel (SUS) screen of 200-mesh, the other is lead (Pb) spheres with a diameter of 0.212- 0.3 mm. The Pb spheres were filled in the low-temperature side of regenerator because the specific heat of Pb is larger than that of SUS at the temperatures below 70 K. Furthermore, two lengths of regenerator, 160 and 200 mm, have been tested. Figure 3 shows the experimental results of dependence of the lowest temperature of regenerators as a function of Pb and SUS ratio. The lowest temperature of the 160 mm regenerator is 21.5 K, and the optimum Pb and SUS ratio is 30:70. In the case of the 200 mm regenerator, lowest temperature is 19.2 K, and the optimum ratio is 20:80. The cooling power measurement shows that the 200 mm regenerator is larger than the 100 mm regenerator. From these results, the 200 mm regenerator shows better performance. However, the pressure loss of the 200 mm regenerator is larger.

These results prove that the regenerator length is an important factor to achieve the high efficiency single stage PTC.

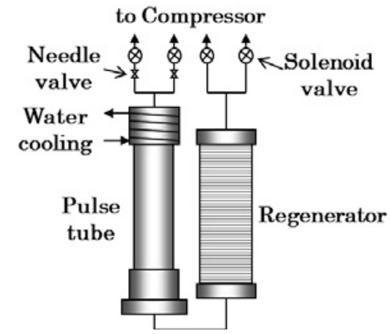

Fig. 1 Schematic of the four-valve pulse tube cryocooler

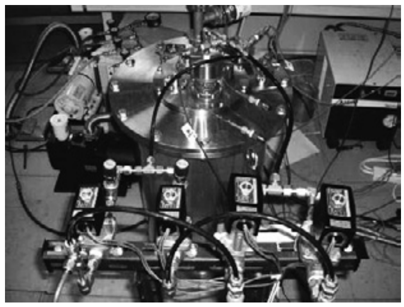

Fig. 2 Photo of the four-valve pulse tube cryocooler at room area

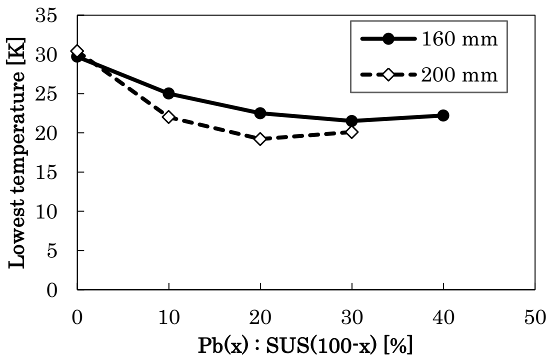

Fig. 3 Dependence of the lowest temperature of two types of regenerators as a function of Pb and SUS ratio

1) Masuyama, S. and Iwamoto, A.: Annual Report of NIFS (Apr. 2011-Mar. 2012) p. 271